Progress Report

Title: *Interactions between agricultural development in southwestern US / northwestern Mexico and the North American Monsoon with a focus on water resources*

Project Duration: 1 May 2004 – 30 April 2007

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Introduction:

Southwestern US and northwestern Mexico are characterized by their arid to semiarid climate and, consequently, anthropogenic activity in that region is highly dependent upon water resources. Understanding the water cycle (which in turn can be affected by anthropogenic activity as well as natural phenomena) and its predictability are key factors for water resources management and, therefore, the socio-economical development and sustainability of that region. The hydroclimate of that region is significantly affected by the North American Monsoon (NAM), which supplies most of the moisture source from the Gulf of California, the Eastern Pacific and the Gulf of Mexico. But population growth and agricultural and urban development is significantly changing the regional landscape, including land cover and soil moisture. Therefore, complex ocean-land-atmosphere interactions may take place in that region and possibly at other locations in North America that are normally affected by the NAM. Three main rivers are originated in that region: the Sonora, the Yaqui and the Mayo. They supply the water to the major urban and agricultural developments in the area.

Project Goals:

The objective of the research proposed here is to study in details the various interactions in the ocean-land-atmosphere system in that region, with a special interest in the NAM system. Focusing on water resources applications, we concentrate on precipitation and river discharge in the Sonora, Yaqui and Mayo river basins. The hydrometeorology of that region is being simulated at a very-high resolution (1 x 1 km^2 horizontal grid size) with the Regional Atmospheric Modeling System (RAMS), for which the hydrology module is being improved to better simulate river discharge in this region. RAMS has been upgraded in its latest version to include a new coordinate system especially designed to improve simulations in complex terrain and it also benefits from the regional reanalysis available since Fall 2003 to force its lateral boundary.

Method:

To address the following five scientific questions: (1) is the current generation of very-high resolution, state-of-the-art mesoscale models capable of simulating the evolution of the NAM in southwestern US / northwestern Mexico; (2) what are the parameters that affect the evolution of the NAM in that region; (3) are these parameters useful for improving the predictability of the NAM and the discharge of the Sonora, Yaqui, and Mayo rivers; (4) has the development of agriculture in that region affected river discharge and the evolution of the NAM through ocean-land-atmosphere interactions and feedbacks; and (5) what is the sensitivity of that region to further rural and urban development in that region; three major tasks are being performed: (1) an evaluation of RAMS performance (with an emphasis on precipitation and river discharge) when used at very-high resolution in that region; (2) a sensitivity analysis of the relative importance of various parameters susceptible of impacting precipitation and river discharge in that region (i.e., sea-surface temperature, soil moisture, land cover) and their interactions with the NAM; and (3) an analysis of the NAM evolution and variability as affected by various scenarios of agricultural and urban development in that region. Special attention will be paid to monthly to interannual variability and how the results of these three tasks are affected by El Niño and La Niña events.

Combining the results from these three tasks, we expect to provide new insights and a much clearer understanding of (1) the evolution of the NAM system and its variations; (2) the response of the warm season atmospheric circulation and precipitation patterns to slowly varying boundary conditions (i.e., SST, soil moisture and vegetation cover); and (3) the role of the NAM system in the regional water cycle and climate variability. Finally, this project will contribute to improving the monthly to interannual prediction of the NAM system and regional water resources and, therefore, it addresses key elements of the PACS/GAPP North American warm season precipitation initiative.

Results and Accomplishments (Year 1: 05/01/2004 – 04/30/2005):

As part of the first task of our project, we identified the data sets that could be used to evaluate the performance of RAMS in simulating precipitation in the region affected by the North American Monsoon (NAM). Several sources of precipitation data are currently available to provide information about the hydrometeorology of that region. These data include measurements from rain gauge networks, ground-based radar, and earth-orbiting satellites. In general, rain gauge data are held to be the most accurate where they are available, but such measurements are sparse or void in regions of complex terrain such as the mountainous regions in the west. Ground Doppler radar estimates are available at a relatively high spatial/temporal scale over much of the U.S. and are able to provide quality precipitation estimates in many regions, but they are impeded or complicated by the presence of topography and are nonexistent over Mexico. Satellite precipitation estimates offer the advantage of increased spatial coverage, including over complex topography. However, they contain a high level of uncertainty that varies over space and time and under different weather regimes, making the error and uncertainty difficult to quantify.

Geostationary satellite infrared precipitation estimates have the advantage of near global coverage between 40º N-S and historical data available over several years. As such, geo-IR products are particularly desirable for climatology studies and for identifying long-term trends. The drawback of IR-based estimates is that they provide only indirect estimates of rainfall and rely on threshold algorithms that are empirically based and not universally valid. Polar-orbiting satellite microwave and radar estimates are more physically based and generally provide high-quality estimates of instantaneous rainfall, but these data are typically provided at a temporal resolution of 1-2 observations per day for a given location.

To meet demand for globally-available, physically-based and accurate precipitation data, merged datasets have been developed that attempt to retain the desirable spatial/temporal features of the geo-IR datasets while drawing data from other sources, such as microwave and radar products, to improve the accuracy of the overall combined dataset. And while these global or near-global merged precipitation products have been developed using the best available data, they are still limited by the uncertainty and spatial/temporal resolution constraints of the raw data products from which they were derived.

In order to extract meaningful information about climatology or weather or to validate numerical model simulations using rainfall data, it is important to understand the strengths and weaknesses of each available data product for the particular area of interest, including a quantitative assessment of random error and bias. This part of our project will provide a comparative investigation of the different sources of precipitation data available for the western U.S. and Mexico and will develop a regional climatology based on these observations. Our goal is to (1) identify the scales of precipitation variability in the west and determine if their relative influence varies by sub-region or evolves over time and under differing synoptic-scale conditions such as El Niño, (2) determine which types of observational data are appropriate for studying the different scales of variability and (3) determine if the degree of uncertainty in precipitation observations is space and/or time dependent. The results of this analysis will be used to identify the dataset or collection of datasets most appropriate for use in forcing a hydrology model over the North American Monsoon Region and for assessing the Regional Atmospheric Modeling System's ability to accurately represent the hydrometeorology of the Western U.S. The study examines precipitation products available for the Western U.S. and Mexico during 1997-2001, a period marked by the strong El Niño event of 1997/1998 and the moderately strong La Niña of 1999/2000. Included in the study are data products developed from rain gauge networks, ground-based radar, geostationary satellite IR sensors, polar orbiting satellite microwave radiometers, and polar orbiting satellite radar measurements.

Several datasets have been selected for inclusion in the study based on the criteria that (1) their spatial domain includes all or part of the Western U.S. and/or Mexico and (2) their temporal domain includes all or part of the 1997-2001 time period. Table 1 shows the selected datasets and their spatial and temporal resolution. Differences in horizontal scale among the data require down- or up-scaling for direct comparison. To date, the majority of the data have been re-gridded to a common 1-degree grid (further downscaling will be required for input into the hydrology model). Preliminary analyses of observations over the NAM region show that the available datasets are generally able to represent the seasonal peak in precipitation associated with the onset of the monsoon (Figure 1). However, there is notable disagreement in the magnitude of observed rainfall. There is also a difference in the observed inner-annual variability among the different data sources. For example, data from the GPCP daily product suggest that the 1998 monsoon season was the wettest over the 1997-2001 period while the NCEP Regional Reanalysis data imply that the 1998 monsoon was relatively normal, receiving approximately the same amount of rain as the 1997 and 1999 seasons. The reasons for these differences are currently being explored by analyzing instantaneous measurements from the TRMM Precipitation Radar. The radar data from TRMM provide information on the 3D structure of individual storms, which will help to identify the weather conditions under which each data set performs well versus those conditions under which they perform poorly. This will help to ascertain whether differences among data products are due to sampling differences or weaknesses in precipitation algorithms. Figure 2 shows the strong degree of rainfall variability characteristic of the North American Monsoon as compared with the variability observed over the North American Continent as a whole. An encouraging result of the preliminary analysis is that the overall mean precipitation over all datasets (Figure 2) is found to compare well with the mean rainfall of ~ 550 mm/yr reported by INEGI (1993) for the state of Sonora.

Table I. Precipitation Datasets and their spatial domain, spatial/temporal resolution and primary data source

Dataset	***Spatial Domain***	***Temporal Resolution***	***Spatial Resolution***	***Data Source***
UEA[a]	*Global*	*Monthly*	*2.5° x2.5°*	*Rain Gauge*
UDEL[b]	*Global*	*Monthly*	*0.5° x0.5°*	*Rain Gauge*
US-MEX[c]	*Regional*	*Daily*	*0.25° x0.25°*	*Rain Gauge*
UWA[d]	*Regional*	*Daily*	*1/8° x 1/8°*	*Rain Gauge*
SSM/I[e]	*Global*	*Pentaday*	*1° x1°*	*Satellite Microwave*
GPI[f]	*40° N-S*	*Daily*	*2.5° x2.5°*	*Satellite IR*
TRMM 3A25[g]	*40° N-S*	*Monthly*	*0.5° x0.5°*	*Satellite Radar*
CMAP[h]	*Global*	*Monthly*	*2.5° x2.5°*	*Merged Product*
GPCP 1DD[i]	*Global*	*Daily*	*1° x1°*	*Merged Product*
GPCP v2[j]	*Global*	*Monthly*	*2.5° x2.5°*	*Merged Product*
TRMM[g]	*Tropical*	*Pentaday*	*1° x1°*	*Merged Product*
NARR[k]	*Regional*	*3-hr*	*32 km*	*Numerical Model*
GR[l]	*Global*	*6-hr*	*2.5°x2.5°*	*Numerical Model*

[a] *University of East Anglia (Hulme 1992 and Hulme 1994);*
http://jisao.washington.edu/data/hulme/
[b] *University of Delaware (Willmott et al., 1994; Willmott and Matsura, 2000);*
http://climate.geog.udel.edu/~climate/
[c] *CPC United States and Mexican Daily Precipitation Analysis:*
http://www.cpc.ncep.noaa.gov/products/precip/realtime/US_MEX/
[d] *University of Washington (Chunmei and Lettenmaier personal communication);*
[e] *Special Sensor Microwave Imager (Ferraro, 1997; Ferraro et al. 2002; McCollum et al. 2002);*
http://lwf.ncdc.noaa.gov/oa/satellite/ssmi/ssmiprecip.html
[f] *GOES Precipitation Index (Arkin and Meisner, 1987)*
[g] *Tropical Rainfall Measuring Mission Satellite (Simpson, et al., 1988; Kummerow et al., 2000; Kummerow et al., 2001);*
http://lake.nascom.nasa.gov/data/dataset/TRMM/01_Data_Products/02_Gridded/index.html
[h] *CPC Merged Analysis of Precipitation (Xie and Arkin, 1996 and 1997);*
http://www.cdc.noaa.gov/cdc/data.cmap.htmli[j] *Global Precipitation Climatology Program (Huffman et al, 1995, 1997; Gruber, 2000)*
[i] *Global Precipitation Climatology Project 1 Degree Daily*
http://www.ncdc.noaa.gov/oa/wmo/wdcamet-ncdc.html
[j] *Global Precipitation Climatology Project Version 2* (*Adler et al, 2003, Huffman et al, 1997*);
http://www.ncdc.noaa.gov/oa/wmo/wdcamet-ncdc.html
[k] *NCEP North American Regional Reanalysis (Messinger et al., 2003);*
http://wwwt.emc.ncep.noaa.gov/mmb/rreanl/index.html
[l] *NCEP Global Reanalysis*

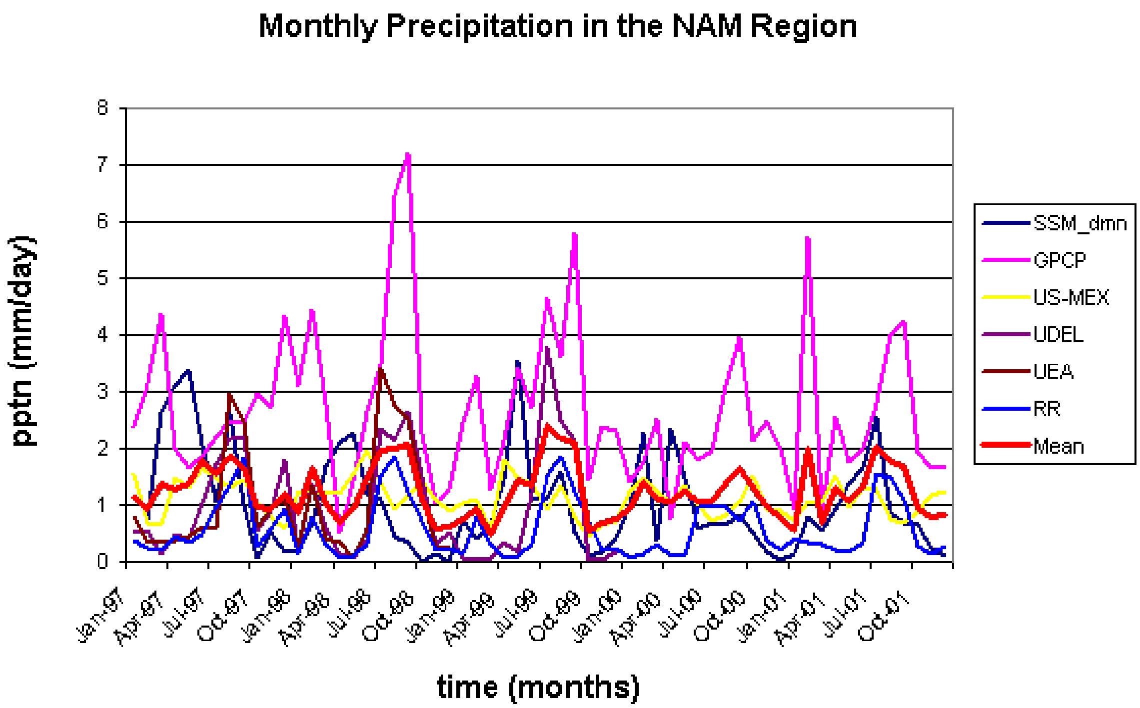

Figure 1. Daily mean precipitation estimates from various databases for the NAM region. The data shown in the figure are from the Special Sensor Microwave Imager (SSMI), GPCP 1 degree daily merged precipitation product (GPCP), CPC U.S. and Mexico Daily Precipitation Analysis (US-Mex), University of Delaware rain gauge product (UDEL), University of East Anglia rain gauge product (UEA), and the NCEP Regional Reanalysis (RR).

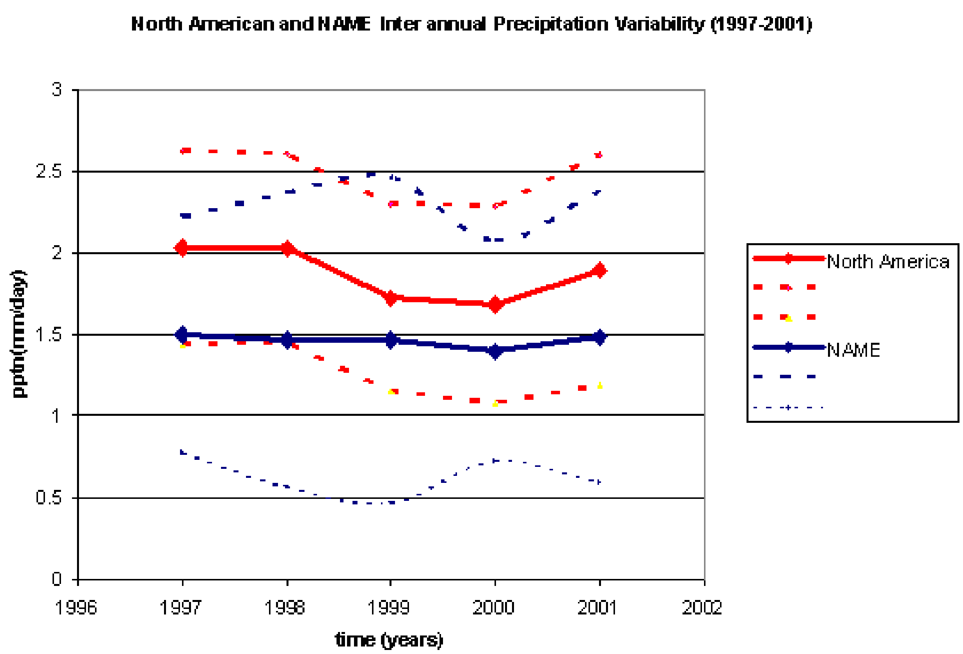

Figure 2. Daily mean rainfall and standard deviation over all datasets illustrating the interannual precipitation variability from 1997 to 2001 for the NAM region and the North American subcontinent.

The eventual goal of this project is to estimate rivers discharges in the NAM region as affected by landscape changes. The core NAM domain is an arid to semiarid region characterized by complex climatology, topography, vegetation, and soil moisture variability. Considering these complexities, only a few rainfall-runoff models can be used in this region. Table II summarizes the various categories of hydrologic models, possibly available for our study. This includes the physically based distributed, semi-distributed, and operational models, which can be either independent or integrated into a soil-vegetation-atmosphere transfer scheme (SVATS).

Distributed models parameterize the surface and subsurface processes in a separate form. SPLASH and HMS consider runoff generation by infiltration and saturation excess, and streamflow production uses the kinematic wave method (Beeson et al. 2001; Yu and Schwartz, 1998, Yu et al. 1999, 2000). These models also parameterize the water and energy transfers between vegetation, soil, groundwater, and channel routing components. The resolution of these models in space and time can be as high as 1 km and 1 hr, respectively, and they are typically applied to the simulation of small watersheds. For river basins like those in the NAM region, this requires the construction of complex parameter databases and high computational costs. Both models are described in the literature, however, neither model is available to the general public.

SACSMA is a lumped model that recently has been implemented in a distributed form (DSACSMA; Franz et al. 2003). This is done through the discretization of the domain. The model runs separately for each sub domain, which is linked by a channel routing model producing the surface runoff flow, interflow and baseflow (Burnash 1995, Marty, 2002). The disadvantage of this model is the lack of a land-surface parameterization, thus restricting its use to operational flood forecast simulations.

Semi-distributed models might provide a computationally affordable option for the NAM river basins (27,000-117,000 km^2). TOPMODEL (Beven and Kirbi 1979, Beven 1982) uses a topographical index to solve the horizontal transport of water due to gravity-driven downslope flow. The flux of water responds to an exponential function that denotes decreasing hydraulic conductivity with depth, and assumes a water table parallel to the ground surface. The required land-cover parameterization is accomplished through the incorporation of TOPMODEL into the LEAF-2 SVATS (Walko et al., 2001). TOPMODEL is a good option to simulate stream flows in steep topographies, which are prevalent in the NAM region. However, some of the fundamental assumptions used in this model limit its application in arid and semi arid environments. Yet, using it, Durand et al (1992) simulated successfully water discharges in the arid regions of France.

Another model that involves the use of SVATS is CLASP. This model parameterizes the soil-vegetation-atmosphere transfers using the SVATS to link the atmospheric and groundwater-surface water schemes (Gutowski et al 2001). The generation of river flow, however, depends on the inputs of the subsurface due to the rising of the water table. This condition is particularly rare in arid and semiarid domains. Aridity is a determining factor in simulating properly the NAM-region-river discharges.

The VIC model possesses a SVATS and it is a semi-distributed model. Through the application of a statistical function describing the infiltration, this model simplifies the representation of the precipitation partition into runoff and infiltration (Liang et al. 1994, 1996). When precipitation is in excess, the infiltration capacity is reached and the runoff is generated; the rest drains gravitationally to the second soil layer to form the baseflow (Figure 3). This function accounts for the heterogeneity of fast runoff generation, which is appropriate in those regions where convective rainfall events (that are sporadic in nature) are dominant. Therefore, we trust that VIC is currently the most appropriate hydrological/SVATS model capable of accomplishing most of the criteria required to simulate the river basins in the NAM region.

To apply VIC in the NAM river basins, Francisco Munoz (the student working on this project) spent two weeks at the Civil and Environmental Engineering Department at Washington University under the supervision of Professors Denis Lettenmaier and Andrew Wood. During this time the model was set up to run hydrological simulations for the Yaqui-Matape, Mayo, and Conchos river basins (Figure 4). Preliminary simulations were produced using the calibration established for the state of Baja California. At this point, individual calibrations and modification of the parameter and forcing databases is in progress. The individual calibrations involve the Yaqui-Matape, Mayo, and Conchos River basins.

Table II. Hydrological Models with possible applications on the NAMS based on the relaxed criteria of selection defined by Beven (2001).

Model	*Classification*	*Parameterization*	*Resolution*	*Time Step*
CLASP[a]	*Physical-Semi Distributed*	*Atmosphere; SVAT;Groundwater*	*Global*	*30min*
DSACSMA[b]	*Operational-Distributed*	*Surface*	*Catchment*	*6 hr*
HMS[c]	*Physical-Distributed*	*Surface; Groundwater; Vegetation; Routing*	*Catchment*	*1 hr*
SACSMA[d]	*Operational-Lumped*	*Surface*	*Regional-Local*	*6 hr*
SPLASH[e]	*Physical-Distributed*	*SVATS*	*Catchment*	
TOPMODEL[f]	*Physical-Semi Distributed*	*Surface; water table*	*Regional-Catchment*	*1 hr*
VIC[g]	*Physical-Semi Distributed*	*Surface; SVATS*	*Regional-Global*	*1 hr*

[a] *Coupled Land-Atmosphere Simulation Program (Gutowski et al. 2002).*
[b] *Distributed Sacramento Soil Moisture Accounting Model (Franz et al. 2003; Carpenter and Georgakakos, 2004).*
[c] *Hydrologic Modeling System (Yu and Schwartz, 1998; Yu et al. 1999; Yu, 2000)*
[d] *Sacramento Soil Moisture Accounting Model (Burnash, 1995, Martin, 2002).*
[e] *Simulator for Processes of Landscapes: Surface/Subsurface Hydrology (Beeson et al. 2001)*
[f] *TOPographic-based MODEL (Beven and Kirby, 1979; ; Bven and Freer, 2001 Beven et al. 1995)*
[g] *Variable Infiltration Capacity Model (Liang et al. 1994 and 1996)*

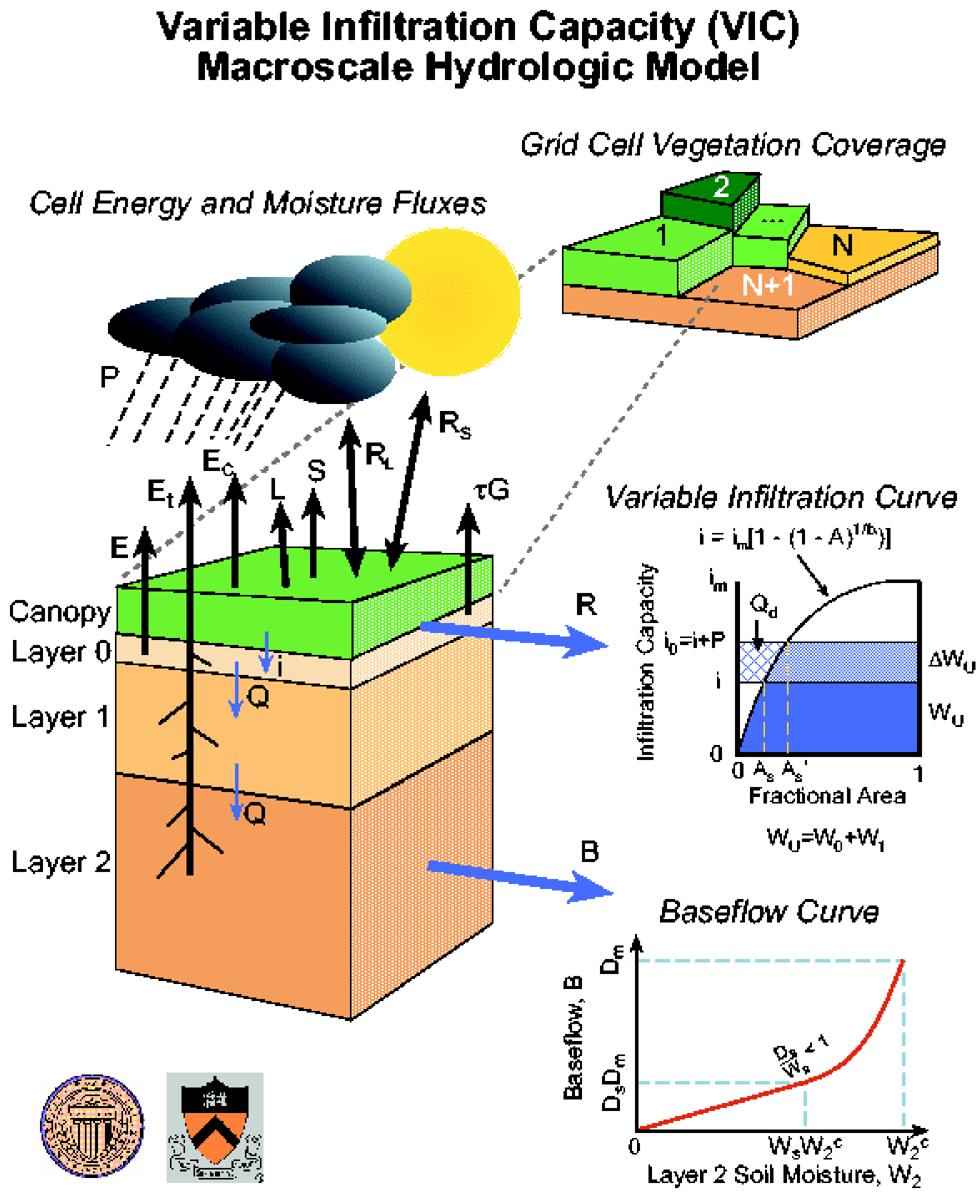

Figure 3. Variable Infiltration Capacity Model (VIC).

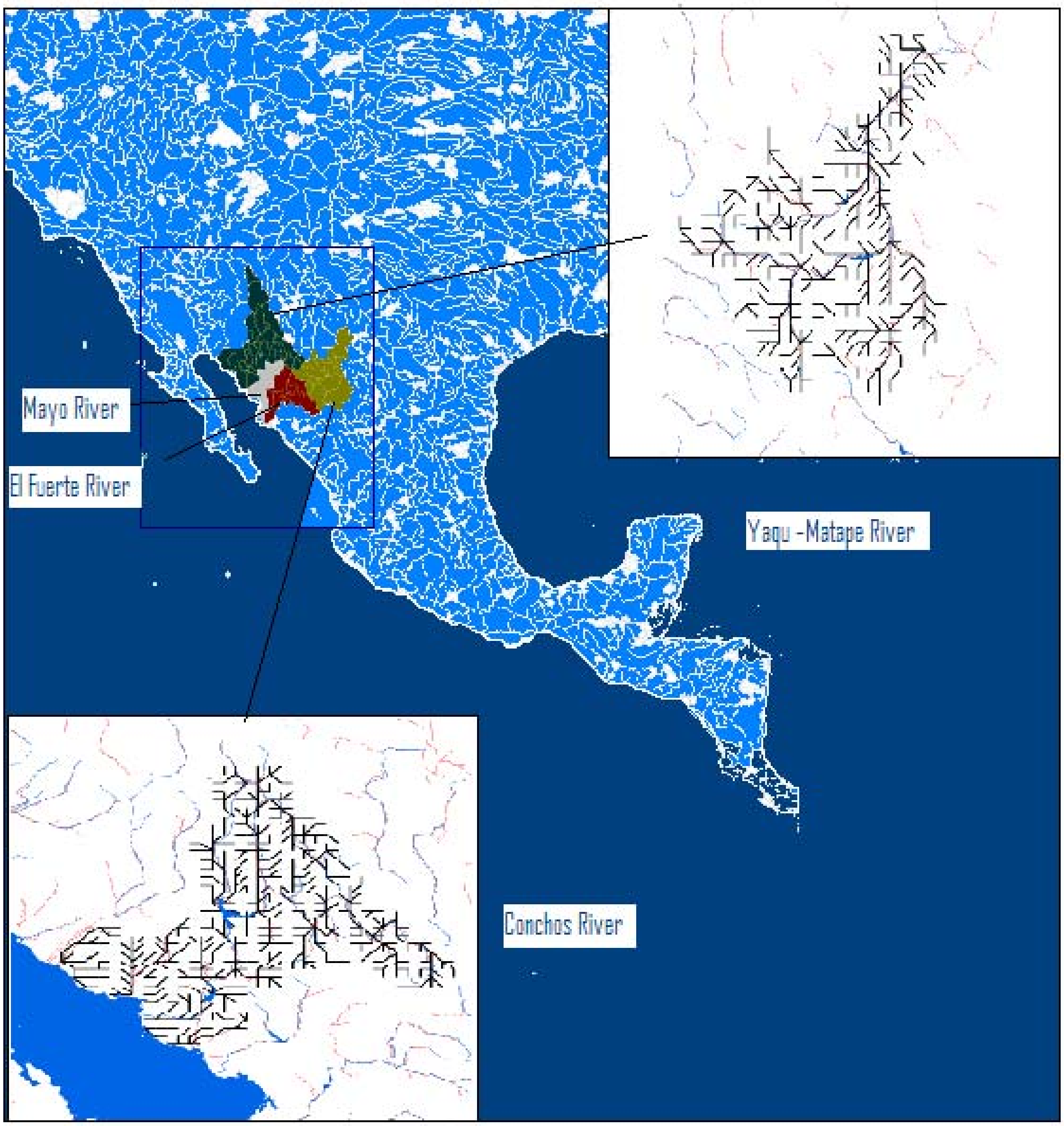

Figure 4. Main drainage basins boundaries (from Hydro 1k) for the NAM hydrological systems; and routing channels for the Yaqui and Conchos Rivers.

References:

Adler, R.F., G. J. Huffman, A. Chang, R. Ferraro, P. Xie, J. Janowiak, B. Rudolf, U. Schneider, S. Curtis, D. Bolvin, A. Gruber, J. Susskind, P. Arkin, and E. Nelkin, 2003: The Version-2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979-Present). *J. Hydrometeor*., **4**, 1147-1167.

Arkin, P.A., and B.N. Meisner, 1987: The Relationship between Large-Scale Convective Rainfall and Cold Cloud over the Western Hemisphere during 1982-84. *Mon. Wea. Rev*., **115**, 51-74.

Beeson. P.C., S. N. Martens and D. D Breshears (2001). Simulating overland flow following wildfire: mapping vulnerability to landscape disturbance. Hydrological Processes. 15: 2917-2930.

Beven K.J. and M.J. Kirkby (1979). A physically based, cariable contributing area model of basin hydrology. Hyydrological Sciences-des Sciences Hydrologiques, 24(1):43-69.

Beven, K., R. Lamb, P. Quin, R. Ramanowics, and J Freer (1995). TOPMODEL. Computer Models of Watershed Hydrology, In: Singh, V.P (Ed) Computer Models of Watersheed Hydrology, pp., 627.

Beven, K. and Freer, J. (2001b). A dynamic TOPMODEL. Hydrological Processes, 15(10): 1993-2011.

Beven, K., J.Freer, B.Hankin, and K. Schulz (2002). The Use of a Generalized Likelihood Measures for Uncertainty Estimation in High-Order Models of Environmental Systems. In: Fitzgerald, W.J., R.L. Smith, A.T. Walden, and P. Young (Eds.) Nonlinear and Nonstationary Signal Processing, pp.115-151.

Burnash, R.J.C., (1995). The NWS River Forecast System in Catchment Modeling, Computer Models of Watershed Hydrology, In: Singh, V.P (Ed) Computer Models of Watersheed Hydrology,. pp. 311-366.Ferraro, R.R., 1997. Special sensor microwave imager derived global rainfall estimates for climatological applications. Journal of Geophysical Research-Atmospheres, 102(D14): 16715-16735.

Ferraro, R. and Q. Li, (2002). Detailed analysis of the error associated with the rainfall retrieved by the NOAA/NESDIS Special Sensor Microwave/Imager algorithm 2. Rainfall over land, Journal of Geophysical Research., 107(D23), 4680, doi:1029/2001JD001172, 2002.

Franz, K.J., Hartmann, H.C., Sorooshian, S. and Bales, R. (2003). Verification of national weather service ensemble streamflow predictions for water supply forecasting in the Colorado River basin. *J. Hydrometeorol.*, 4(6): 1105-1118.

Gruber, A., X. Su, M. Kanamitsu, and J. Schemm (2000). The comparision of two merged rain gauge-satellite precipitation datasets. Bulletin of the American Meteorological Society, 81(11): 2631-2644.

Gutowski, W. J. et al., (2002). A coupled land-Atmosphere Simulation Program (CLASP): Calibration and Validation. *J. Geophys. Res.*, 107(D16): ACL 3-1-3-17.

Huffman, G. J., R.F. Adler, B. Rudolf, U. Schneider, and P.R. Keehn (1995) Global precipitation estimates based on a technique of combining satellite-based estimates, rain gauge analysis, and NWP model precipitation information. Journal of Climate, 8, 1284-1295.

Huffman, G.J. R.F. Adler, P. Arkin, A. Chang, R. Ferraro, A. Gruber, J. Janowiak, A.McNab, B. Rudolf, and Udo Schneider 1997. The Global Precipitation Climatology Project (GPCP) Combined Precipitation Dataset. Bulletin of the American Meteorological Society, 78(1): 5-20.

Hulme, M., 1992. A 1951-80 Global Land Precipitation Climatology for the Evaluation of General-Circulation Models. Climate Dynamics, 7(2): 57-72.

Hulme, M. (1994). Validation of large-scale precipitation fields in GCMs. In: Global Precipitations and Climate Change (Eds. Desbois, M and F. Désalmand, F.): 387-406.

INEGI (1993). Estudio Hidrológico del Estado de Sonora. Instituto Nacional de Estadística Geografía e Informática.

Kummerow, C. et al., 2000. The status of the Tropical Rainfall Measuring Mission (TRMM) after two years in orbit. Journal of Applied Meteorology, 39(12): 1965-1982.

Kummerow, C. et al., 2001. The evolution of the Goddard profiling algorithm (GPROF) for rainfall estimation from passive microwave sensors. Journal of Applied Meteorology, 40(11): 1801-1820.

Liang, X., Lettenmaier, D.P. and Wood, E.F. (1996). One-dimensional statistical dynamic representation of subgrid spatial variability of precipitation in the two-layer variable infiltration capacity model. *J. Geophys. Res.*, 101(D16): 21403-21422.

Liang, X., Lettenmaier, D.P., Wood, E.F. and Burges, S.J. (1994). A Simple Hydrologically Based Model of Land-Surface Water and Energy Fluxes for General-Circulation Models. *J. Geophys. Res.*, 99(D7): 14415-14428.

Martin, K. (2002) NWSRFS calibration parameter selection and Geologic Reasoning: Pacific northwest cases. *J. Amer. Water Res. Association*, 38(5): 1349-1362.

McCollum, J.R., W.F. Krajewski, R.R. Ferraro, and M.B. Ba (2002). Evaluation of biases of satellite rainfall estimation algorithms over the continental United States, Journal of Applied Meteorology, 41: 1065-1080.

Simpson, J., Adler, R.F. and North, G.R., 1988. A Proposed Tropical Rainfall Measuring Mission (Trmm) Satellite. Bulletin of the American Meteorological Society, 69(3): 278-295.

Willmott, C.J., S.M. Robertson and J.J. Freddema, (1994). Estimating continental and terrestrial precipitation averages from rain-gauge networks. International Journal of Climatology. 14(4): 403-414.

Willmott, C.J. and K. Matsuura, (2000). http://climate.geog.udel.edu/~climate/html_pages /README.ghcn_clim.html.

Xie, P.P. and Arkin, P.A., 1996. Analyses of global monthly precipitation using gauge observations, satellite estimates, and numerical model predictions. Journal of Climate, 9(4): 840-858.

Xie, P.P. and Arkin, P.A., 1997. Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. Bulletin of the American Meteorological Society, 78(11): 2539-2558.

Yu, Z, (2000). Assessing the response of subgrid hydrologic processes to atmospheric forcing with a hydrologic model system. *Global and Planetary Change*. 25: 1-17.

Yu, Z, and F. W. Schwartz, (1999). Automated calibration applied to watershed-scale flow simulations. *Hydrological Processes*. 13: 191-209.

Yu, Z, M.N. Lakhtakia, and E.J. Barron, (1999). Modeling the river-basin response to single-storm events simulated by a mesoscale meteorological model at various resolutions. *J. Geophys. Res.*, 104 (16): 19675-19689.

Future Work (Year 2: 05/01/2005 – 04/30/2006):

We are progressing with our plan as established in our original proposal. This year, we will focus on the evaluation of RAMS performance (with an emphasis on precipitation and river discharge) when used at very-high resolution in that region. For that purpose, state-of-the-art precipitation observations have been collected and are being analyzed (see above). As part of this part of the project, we expect to produce a very-high resolution precipitation dataset (gridded at 1 by 1 km^2) and clarify fundamental processes involved in land-atmosphere interactions in that region. In parallel to that part of the study, we will perform a sensitivity analysis of the relative importance of various parameters susceptible of impacting river discharge in that region with the VIC model.

Publications from this project:

Goris, K., Munoz-Arriola, F. and R. Avissar. Spatial and temporal variability of rainfall in the region affected by the North American Monsoon. In preparation.

Munoz-Arriola, F. and R. Avissar. Ensemble prediction of the Sonora, Yaqui, and Mayo river discharges. In preparation.

Baidya Roy, S. and R. Avissar. The hydroclimatology of the region affected by the North American Monsoon. In preparation.

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